TVS-AP-81-114

Transit Demand Forecasting for Individual Bus Routes

Ontario

Ministry of
Transportation and
Communications

Policy
Planning and
Research Division

TVS-AP-81-114

Transit Demand Forecasting for Individual Bus Routes

J.J. Hajek
J.W. Wong
Research Officers
Transport and Vehicle Systems Office
Research and Development Branch

Published by:
The Policy Planning and Research Division
Ontario Ministry of Transportation and Communications
Hon. James W. Snow, Minister
H.F. Gilbert, Deputy Minister

Published without prejudice
as to the application of the findings.
Crown copyright reserved; however, this
document may be reproduced for non-commercial
purposes with attribution to the Ministry.

For additional copies write:
The Editor
Research and Development Branch
Ministry of Transportation and Communications
1201 Wilson Avenue
Downsview, Ontario
M3M 1J8

November 1981

ABSTRACT

This report describes the development, calibration, and testing of transit demand models for prediction of bus ridership on individual bus routes in Metropolitan Toronto. The model predictions can be used for analysis of alternative routes, alignments, and schedules.

Three direct trip generation and attraction models were constructed using a least squares technique. One model was constructed for the prediction of inbound-on trips (boardings in the direction of the CBD) and two models for the prediction of outbound-on trips. Combined, the models enable calculation of directional loadings on any bus route section.

All land use variables available for the Metropolitan Toronto area were reviewed and their influence on transit usage was investigated. The car ownership (number of car-owning and non-car-owning households) was identified as the most important variable for prediction of transit ridership.

The model structure developed for Metropolitan Toronto may be used for other urban areas; the model's coefficients, however, should be obtained by calibration utilizing local data.

CONTENTS

1.0 INTRODUCTION 1

2.0 REVIEW OF PREVIOUS WORK 4
2.1 Shortreed Model 4
2.2 Simplified Approach 7

3.0 DATA BASE 10
3.1 Description of Bus Routes 10
3.2 Data Collection 10
3.3 Source of Data 18

4.0 BASIC VARIABLE RELATIONSHIPS 20
4.1 Ridership Data 20
4.2 Household Variables 21
4.3 Other Variables 25

5.0 MODEL DEVELOPMENT 26
5.1 Inbound-On Model 27
5.2 Outbound-On Models 31
5.2.1 Outbound-On, Model A 31
5.2.2 Outbound-On, Model B 33

6.0 DATA DEFICIENCIES 37

7.0 SUGGESTED MODEL USE 40

8.0 CONCLUSIONS AND RECOMMENDATIONS 41

9.0 ACKNOWLEDGEMENTS 42

10.0 REFERENCES 43

LIST OF TABLES

1/ Route Description 11

2/ Detailed Route Description 12

3/ Simple Regression Coefficients 22

4/ Statistical Parameters 29

LIST OF FIGURES

1/ Comparison of Models 6

2/ Headway Factor 9

3/ Toronto Transit Commission Bus Routes Included in the Study 15

4/ Inbound-On Model 28

5/ Comparison of Observed and Predicted Ridership, Inbound-On, 1976 30

6/ Outbound-On, Model A 32

7/ Comparison of Observed and Predicted Ridership, Outbound-On, Model A 34

8/ Outbound-On, Model B 35

9/ Comparison of 1976 and 1977 Ridership Counts (Observed Ridership) 38

1.0 INTRODUCTION

This report summarizes research efforts directed toward the development of a transit demand model for individual bus routes by the Transport and Vehicle Systems Office, Research and Development Branch of the Ministry of Transportation and Communications (MTC). The objectives were to develop a transit demand model capable of predicting potential ridership on new or extended bus routes, and ridership changes due to changes in route alignment and service levels.

The prerequisites were the determination of available land use and level-of-service variables and user attributes necessary for the model development. The term "available" should be emphasized. A considerable number of level-of-service and user attributes are known to influence transit ridership. These include: population, car ownership, income, development density and characteristics, route orientation toward employment opportunities, travel time ratio, travel economy, ride quality, social image, transportation model reliability, comfort and convenience, and marketing and information services. However, data on all these factors are not available to the model builder and, particularly, to the model user. Furthermore, not all factors are amenable for inclusion in mathematical models.

Emphasis in the model development was placed on the compatibility of the prediction methodology with aspects such as:

a. availability and reliability of data,
b. practical requirements for prediction accuracy,
c. simplicity of use, and
d. time and effort required to obtain model predictions.

In the literature, the advantages and disadvantages of aggregate versus disaggregate modelling techniques have been analysed (1,2),comprehensive critiques of the present urban transportation models and modelling techniques have been presented (3,4), and considerable research effort has been directed toward the development of behavioral disaggregate models (5). This work cannot be reviewed here; suffice it to say that the art of theoretical model formulation and construction is quite advanced and that the parameters these models should meet and the policy issues they should address are well identified. However, there is a startling lack of practical operational models which can be used (by transit planners and transit operators) to obtain ridership figures on individual bus routes (6).

The models described herein address the principal issues of responsiveness to the basic land use variables and service attributes, practical usefulness, and prediction accuracy. No systematic attempt was made to model complex behavioral

relationships which would enable:

a. evaluation of the model response to non-transit events (e.g., increase in the price of gasoline or parking);

b. full transferability of models between different-size cities; and

c. evaluation of differing assumptions regarding more qualitative variables such as comfort and convenience and marketing and information services.

The transit demand models developed in this study can be classified as direct demand, empirical, transit trip generation, and attraction models predicting total daily ridership on individual bus routes or bus route sections during a typical weekday.

2.0 REVIEW OF PREVIOUS WORK

2.1 Shortreed Model

The study builds on previous work by Shortreed (7) and Maynes (8), who developed a transit demand model for predicting bus ridership on a route-by-route basis utilizing available land use data.

The Shortreed model was calibrated and tested for the following cities and bus routes:

a. Austin, Texas - 4 selected routes
b. Guelph, Ontario - all routes
c. Kitchener-Waterloo, Ontario - 16 selected routes
d. Metropolitan Toronto, Ontario - 3 selected routes

The bus routes were divided into sections. The sections were generally 800 m to 1600 m (1/2 mile to 1 mile) long and were homogeneous with respect to headways, overlapping routes, and general service characteristics. They were not homogeneous with respect to land use. The following variables were obtained for each section.

a. number of target households in primary area
b. number of target households in secondary area
c. number of other households in primary area
d. number of other households in secondary area
e. total employment within 230 m (750 ft) of bus service

f. retail employment within 230 m (750 ft) of bus service

g. school enrollment within 230 m (750 ft) of bus service

h. headways

The target households were defined as households with a 1971 annual income of less than $6000 or, in the case of Metropolitan Toronto, as non car-owning households. The other households were defined as households with a 1971 income of over $6000 or, in the case of Metropolitan Toronto, as car-owning households. The primary area was defined as the area having bus service within 150 m (500 ft); the secondary area had bus service within the range of 150 m to 300 m (500 ft to 1000 ft).

The Shortreed model estimates the number of boarding or alighting passengers per route section and direction during four different time periods (morning peak period, midday, afternoon peak period, and night) using a modified gravity model without a deterrent function. During the model review, it became apparent that despite the number of land use variables included in the model and the model's logical behavioral relationships, the prediction power of the model was quite limited. This is illustrated in Figure 1 which compares the observed ridership on the three Metropolitan Toronto bus routes (Bathurst, Cummer, and Eglinton West) with the ridership predicted by the Shortreed model. The ridership is in terms of the total daily number of passengers boarding

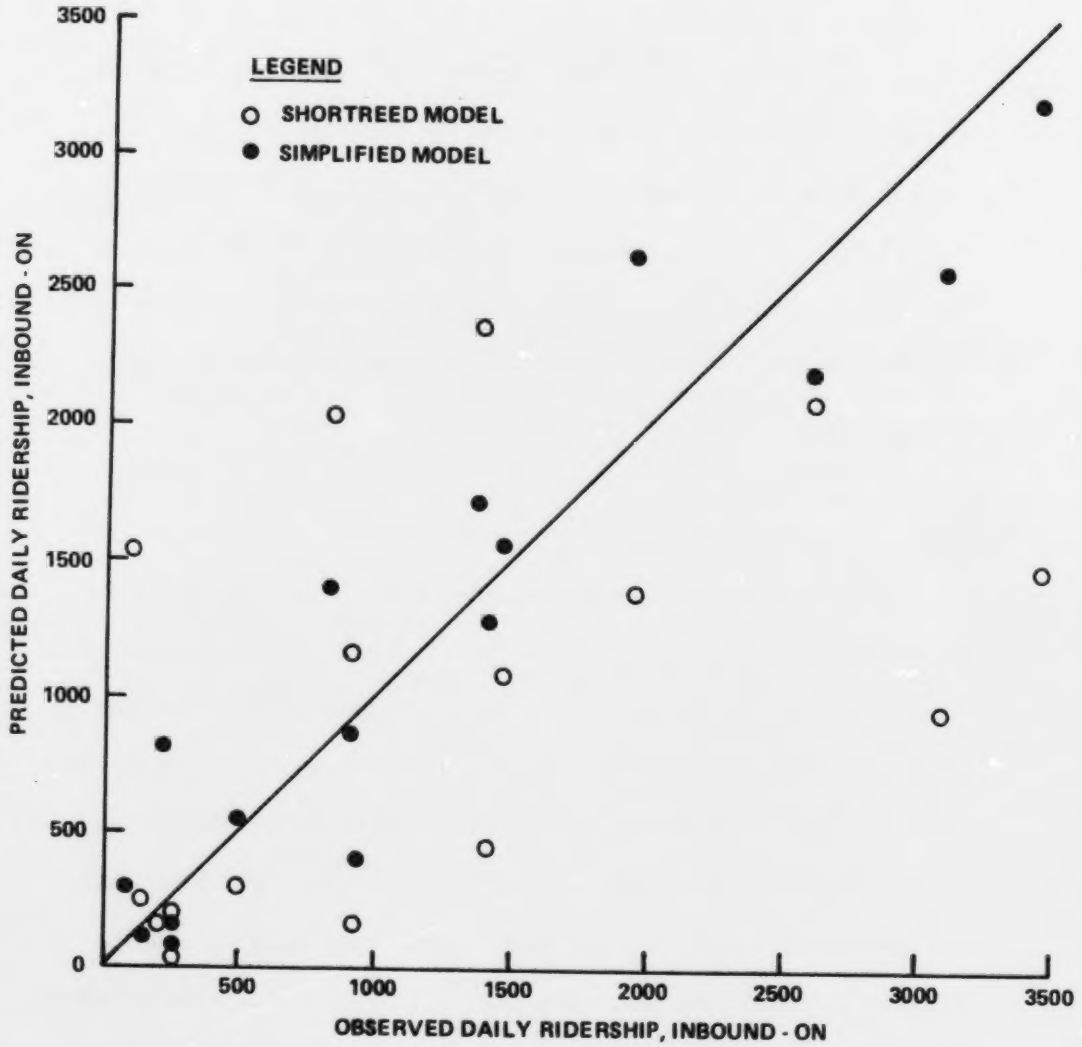

Figure 1/ Comparison of Models

buses (travelling toward the CBD) within a bus route section. Also shown in Figure 1 are ridership predictions obtained by a simplified transit trip generation model, whose development is described below.

2.2 Simplified Approach

It was found that a considerable improvement in prediction accuracy can be achieved by concentrating on trip generation and attraction variables without including complex spatial distribution and modal split variables and relationships. Using the data collected by Shortreed, simple, direct transit demand models were developed in an internal MTC R/D study for Austin, Guelph, Kitchener-Waterloo, and for the three Metropolitan Toronto routes. For example, the model based on the three Toronto routes predicting loadings in the direction of the Central Business District (CBD) is given below:

$$IN\text{-}ON = -717 + 4.7\,NH + 0.33\,SCH + 568\,HF \qquad (1)$$

where:

IN-ON = total daily number of passengers boarding inbound buses (buses travelling toward the CBD) within a route section. This number should always be greater than 0.

NH = number of non car-owning households within 300 m (1000 ft) of bus service per route section.

SCH = secondary and post-secondary school enrollment within

230 m (750 ft) of bus service per route section. (Primary school students are not expected to use public transportation.)

HF = headway factor for peak period. The headway factor is defined in Reference 8 and is presented as a function of the headway in Figure 2.

Ridership predicted by the above model was compared with observed ridership in Figure 1. The model fit illustrated in Figure 1, as well as the statistical parameters of the model based on a least squares technique (R = 0.94, standard error = 420 trips, mean estimate = 1223 trips), suggest that the model has reasonable predictive power and a potential for practical application. Since the model was based on rather limited data (only three routes serving predominantly residential areas; absence of available structural-type household variables), it was decided to test the simplified transit demand modelling approach on a more extensive bus route sample in Metropolitan Toronto. The procedure used and results achieved in this endeavour are described in the following sections.

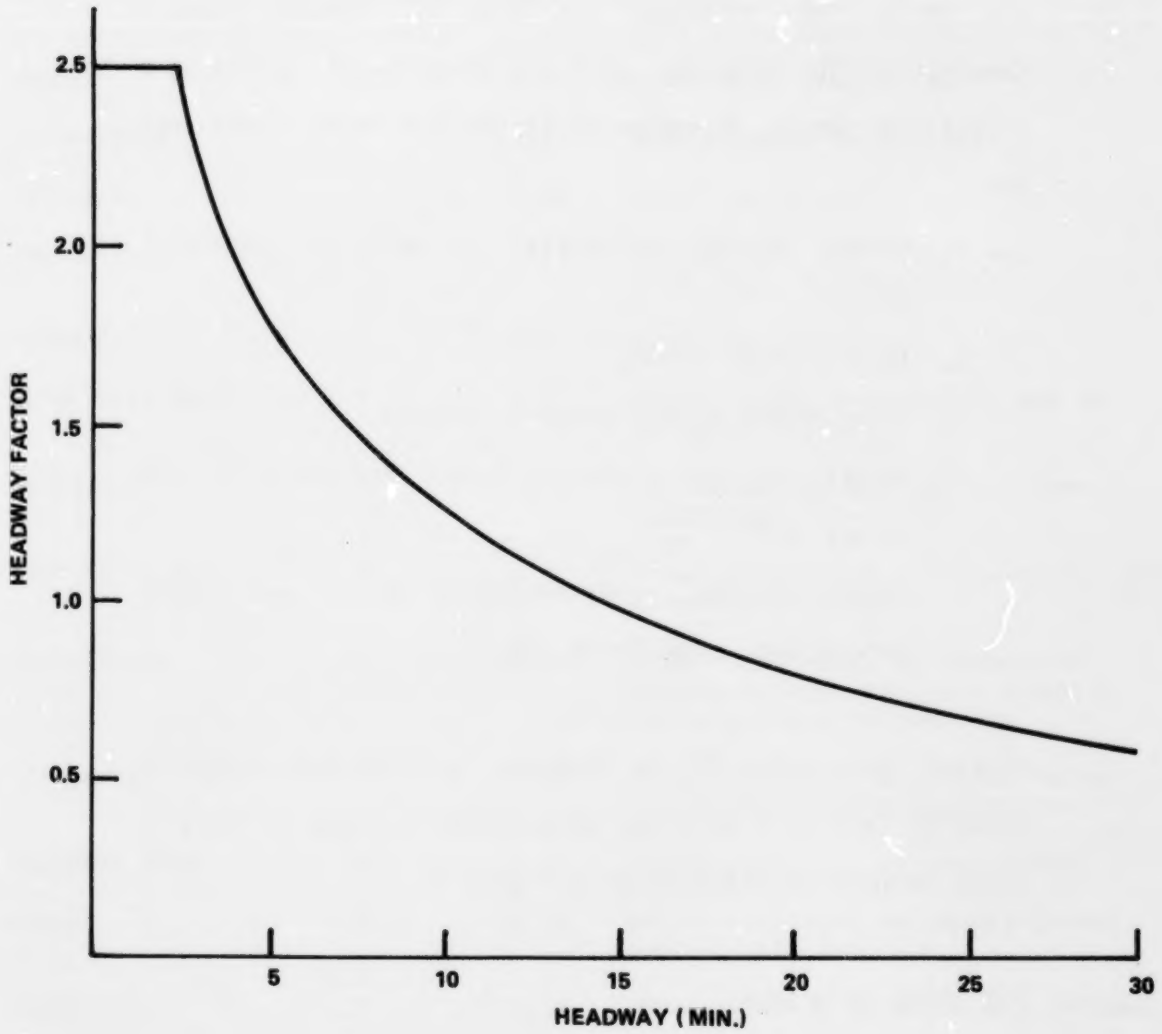

Figure 2/ Headway Factor (According to Reference 8)

3.0 DATA BASE

3.1 Description of Bus Routes

Thirteen bus routes in Metropolitan Toronto were selected for the study. The selection was made by Toronto Transit Commission (TTC) personnel with the objective of obtaining a diversified sample encompassing various bus route types such as:

a. routes serving residential as well as industrial areas,
b. local, feeder routes,
c. major routes on main arterial streets,
d. routes with and without a direct connection to the subway, and
e. routes serving newly-developed areas and routes serving old, established areas.

A brief description of the thirteen selected bus routes is given in Table 1, a detailed description is given in Table 2. Route location is illustrated in Figure 3.

3.2 Data Collection

The bus routes were divided into sections varying in length from 300 m to 4600 m (1000 ft to 15000 ft). The division

TABLE 1/ROUTE DESCRIPTION

ROUTE NAME	NUMBER OF SECTIONS	LENGTH (km)	DESCRIPTION & SPECIAL FEATURES
Cummer	9	10.45	High income residential
Forthbridge	1	1.89	Middle income residential
Islington	9	13.01	Mixed residential
Queensway	6	6.70	Residential, industrial, and commercial, Sherway Garden
Rosedale	3	3.47	Mixed residential
Royal York South	5	5.57	Middle income residential, and two secondary schools
Greenwood	2	1.89	Low income residential, and some industrial
Kipling South	6	6.27	Mixed residential and industrial, two secondary schools
Mall Circle	10	17.68	Mixed residential and industrial, Sherway Garden, Queensway Hospital and three secondary schools
Birchmount	7	11.82	Mixed industrial and middle income residential, one secondary school
Eglinton West	13	24.11	Mixed industrial and residential
Warden	7	11.32	Mixed industrial and middle income residential, hospital
Finch East	8	12.34	Mixed residential and Seneca College

TABLE 2/DETAILED ROUTE DESCRIPTION

ROUTE NAME	SECTION NO.	SECTION CLASS.*	AM PEAK HEADWAY (MIN)	DISTANCE FROM SUBWAY (km)	TOTAL LENGTH (m)	SCHOOL ENROLLMENT	RATIO OF DWELLING UNITS & EMPLOYMENT OPPORTUNITIES
CUMMER	1		7.5	0.16	300		
	2	R	7.5	0.64	732	0	1.26
	3	R	7.5	1.77	1524	773	2.32
	4	R	7.5	3.06	1067	0	2.58
	5	R	7.5	4.02	1067	495	5.56
	6	R	7.5	5.31	1524	739	6.18
	7	I	7.5	6.60	1433	0	0.40
	8	R	7.5	9.01	1371	0	2.79
	9	R	7.5	8.21	1433	0	17.87
FORTHBRIDGE	1	R	10.0	4.34	1890	0	16.25
ISLINGTON	1		4.0	0.16	300		
	2	R	4.0	1.29	1615	0	2.00
	3	R	4.0	3.06	1890	603	6.84
	4	R	4.0	4.83	1890	0	10.46
	5	I	4.0	6.28	1372	1282	0.97
	6	I	4.0	8.21	1524	0	0.53
	7	R	8.0	9.33	1524	859	2.69
	8	R	8.0	10.62	914	0	1.97
	9	R	8.0	12.23	1981	0	5.55
QUEENSWAY	1		11.3	3.70	300		
	2	R	11.3	3.06	1280	0	1.42
	3	I	11.3	2.90	945	356	0.64
	4	I	11.3	4.02	1372	0	0.20
	5	I	11.3	5.47	1372	0	0.02
	6	I	11.3	6.60	1433	0	0.00
ROSEDALE	1		6.0	0.16	300		
	2	R	6.0	0.80	1646	0	12.87
	3	R	6.0	2.57	1524	0	42.45

TABLE 2 - (cont'd)

ROUTE NAME	SECTION NO.	SECTION CLASS.*	AM PEAK HEADWAY (MIN)	DISTANCE FROM SUBWAY (km)	TOTAL LENGTH (m)	SCHOOL ENROLLMENT	RATIO OF DWELLING UNITS & EMPLOYMENT OPPORTUNITIES
ROYAL YORK	1		7.3	0.16	300		
SOUTH	2	R	7.3	0.80	914	0	10.91
	3	R	7.3	1.93	975	1367	1.84
	4	R	7.3	3.22	1554	0	1.45
	5	R	7.3	4.83	1829	481	14.62
GREENWOOD	1		6.0	0.16	300		
	2	R	6.0	0.80	1585	100	2.36
KIPLING	1		5.8	0.16	300		
SOUTH	2	I	5.8	1.45	1219	100	0.11
	3	I	5.8	2.57	1676	0	0.01
	4	I	5.8	3.86	1250	0	0.11
	5	I	5.8	5.15	1219	0	0.00
	6	I	5.8	6.11	610	1047	0.85
MALL CIRCLE	1		20.0	9.65	1219		
	2	R	20.0	8.85	914	0	1.49
	3	I	20.0	7.56	2743	0	0.04
	4	I	20.0	4.51	1646	0	0.41
	5	R	20.0	5.47	975	0	4.98
	6	R	20.0	7.08	1006	1156	1.07
	7	R	20.0	8.05	4237	0	11.82
	8	I	20.0	4.51	1890	421	0.39
	9	I	20.0	3.86	914	0	0.27
	10	I	20.0	5.63	2134	0	0.09
BIRCHMOUNT	1		6.0	0.16	300		
	2	I	6.0	2.41	3840	0	0.80
	3	I	6.0	4.99	1646	0	0.33
	4	I	12.0	6.44	1067	0	0.27
	5	R	12.0	7.72	1920	1562	2.89
	6	R	12.0	9.17	1524	0	13.62
	7	R	12.0	11.26	1524	0	7.34

TABLE 2 - (cont'd)

ROUTE NAME	SECTION NO.	SECTION CLASS.*	AM PEAK HEADWAY (MIN)	DISTANCE FROM SUBWAY (km)	TOTAL LENGTH (m)	SCHOOL ENROLLMENT	RATIO OF DWELLING UNITS & EMPLOYMENT OPPORTUNITIES
EGLINTON WEST	1		2.3	0.16	300		
	2	R	2.3	1.13	1524	690	2.28
	3	R	2.3	2.57	1402	0	1.98
	4	R	2.3	3.54	762	0	3.73
	5	R	7.5	5.15	1981	0	2.77
	6	I	7.5	7.08	2133	375	0.09
	7	R	7.5	9.49	2286	0	41.50
	8	R	7.5	11.42	2133	302	13.26
	9	R	7.5	13.03	1219	625	16.19
	10	I	18.0	16.89	4572	0	0.00
	11	I	18.0	19.97	2743	0	0.00
	12	R	9.0	6.78	1524	375	1.04
	13	I	9.0	8.21	1524	0	0.39
WARDEN	1		4.0	0.16	300		
	2	I	4.0	1.13	1524	300	0.00
	3	I	4.0	3.06	1890	0	0.57
	4	R	4.0	4.67	1646	0	2.59
	5	I	4.0	6.11	1067	0	0.61
	6	R	8.0	7.40	1920	0	8.15
	7	R	8.0	9.33	2972	1692	1.37
FINCH EAST	1		2.8	0.16	300		
	2	R	2.8	1.13	1524	0	5.41
	3	R	2.8	2.90	2134	0	20.54
	4	R	2.8	4.51	1524	4800	4.51
	5	R	5.5	6.28	1524	0	20.02
	6	R	5.5	7.88	1524	0	3.31
	7	R	5.5	9.33	1524	0	5.84
	8	R	5.5	11.26	2286	0	24.14

* Section classification is based on a ratio defined as the total number of dwelling units in the section divided by the total number of section's employment opportunities
if ratio $\leq$ 1.0, section is considered industrial (I)
if ratio $>$ 1.0, section is considered residential (R)

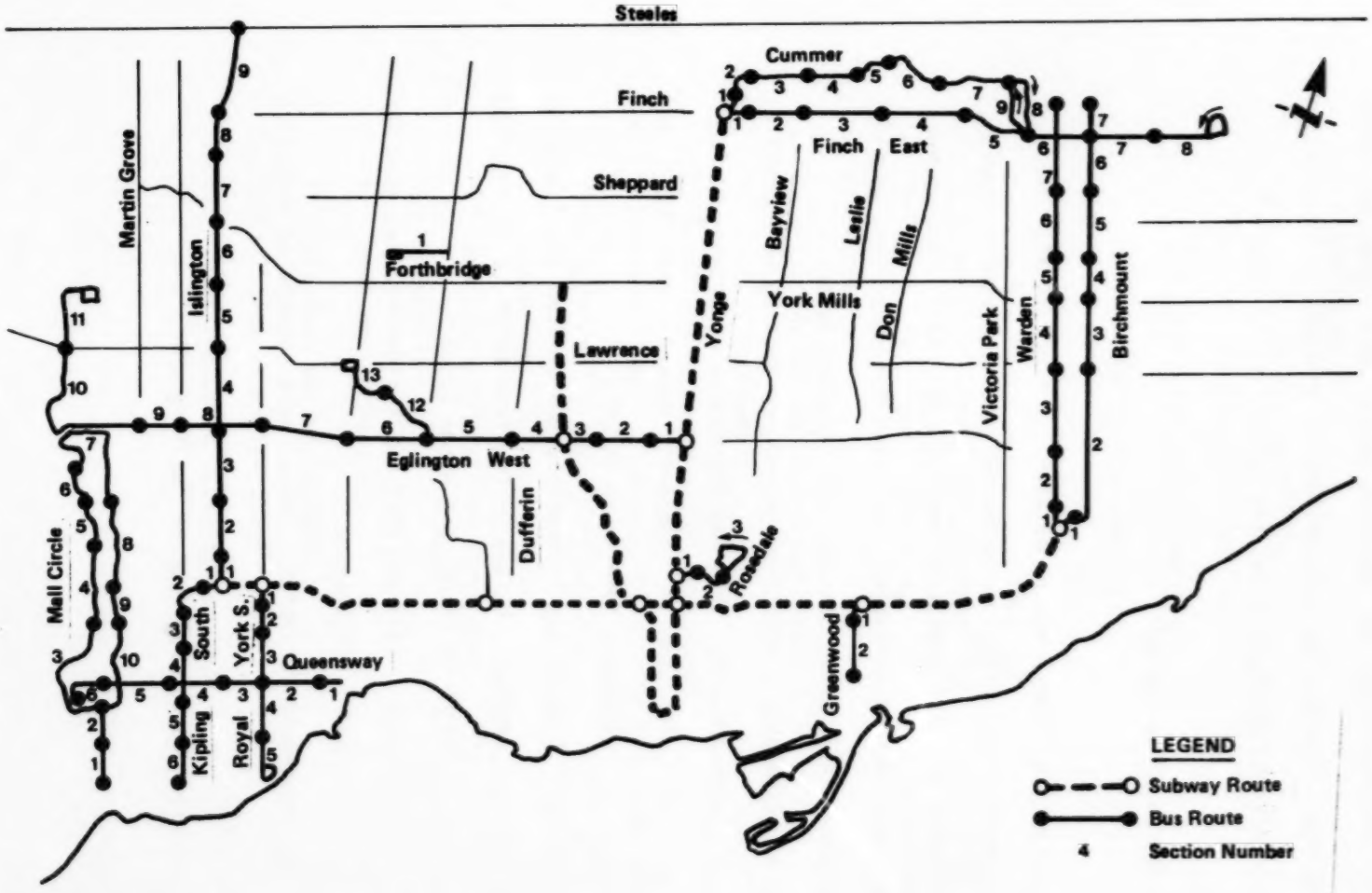

Figure 3/ Toronto Transit Commission Bus Routes Included in the Study

was done according to the principles outlined in Section 2.1. It was assumed that a bus rider would not board and alight the bus within the same section. In total, the thirteen routes were divided into 86 sections which were used as basic sampling units in the data collection process. The sections are described in Table 2 and are identified in Figure 3.

Selection of Variables

An extensive search was undertaken to identify all land use and spatial-separation variables related to transit ridership available for Metropolitan Toronto, and their best sources. The final list of variables collected for each route section, together with a brief description, is given below.

a. Ridership - number of passengers getting on and off at each bus stop. This was segregated according to:
   i) direction - inbound, toward the CBD, and outbound, toward the suburbs
   ii) time of day - ridership was defined for four time periods: before 09:00, from 09:00 to 16:00, from 16:00 to 19:00, and after 19:00
   iii) year - 1976 and 1977 (1976 ridership was used for model calibration.)

b. Household Variables - These were segregated according to:
   i) structural type of dwelling unit:

- single family houses
- multiple dwelling units (up to six units)
- apartments

ii) car ownership:

- car-owning households
- non car-owning households

iii) distance to bus route service:

- 0 to 150 m (0 to 500 ft)
- 150 to 300 m (500 to 1000 ft)
- 300 to 600 m (1000 to 2000 ft)

c. Employment - within 230 m (750 ft) of bus route service. This was obtained for the following categories:

i) factory and warehouse employment

ii) retail employment

iii) office and unclassified employment

d. School Enrollment - within 230 m (750 ft) from bus route service. This was obtained for:

i) secondary school enrollment

ii) post secondary school enrollment

e. Bus Headways

i) peak period headways

ii) off-peak period headways

f. Spatial Separation Variables

i) total transit travel time to CBD

ii) travel time ratio (transit travel time/auto travel time)

iii) travel time difference (auto travel time - transit travel time)

iv) distance of bus route section to subway or subway connector

3.3 Source of Data

All data were readily available.

Bus ridership data were obtained from the Toronto Transit Commission. The TTC data are very comprehensive: number of passengers getting on and off at each bus stop is given for four time periods (before 09:00, 09:00 to 16:00, 16:00 to 19:00 and after 19:00).

Dwelling units, segregated according to the structural type and the distance to bus service (bus stops), were obtained from a 1976 Metropolitan Toronto survey. The structural type of dwelling units was known for each survey block. The survey block area was usually only 10 000 m^2. Household car ownership data were obtained from the 1971 census and were known only for census tracts. The census tracts are considerably larger than the survey blocks and may contain up to several thousand dwelling units.

Employment data were obtained from the 1976 Metropolitan Toronto survey. Data were available on a survey block basis. School enrollment data were obtained by contacting local school boards. Spatial-separation variables were obtained from transit time-tables, maps, and Metropolitan Toronto planning studies, as required.

In the case of intersecting and parallel routes, household, employment, and school enrollment data were assigned to individual routes in proportion to the total transit travel time required to reach a major destination (subway or subway connectors).

4.0 BASIC VARIABLE RELATIONSHIPS

4.1 Ridership Data

Ridership data, originally obtained for the four different time periods, were aggregated into total daily ridership figures. The prediction of transit ridership for four different weekday time periods may be considered impractical and unnecessary since ridership figures for different periods are usually highly correlated and for comparison purposes (comparison of alternative routes or route alignments) the total daily ridership may actually be preferable. Also, ridership on certain route sections during off-peak periods is often insignificant.

For modelling purposes, the ridership variables (dependent variables) were defined as follows.

IN-ON - total daily ridership boarding inbound buses (buses travelling towards the CBD) per route section, (inbound-on)

IN-ONr - total daily ridership, inbound-on, per 300 m (1000 ft) long route segment

OUT-ON - total daily ridership boarding outbound buses (buses travelling away from the CBD) per route section, (outbound-on)

OUT-ONr - total daily ridership, outbound-on, per 300 m (1000 ft) long route segment

Basic variable relationships were studied using variables IN-ON and OUT-ON; the models predict ridership in terms of variables IN-ONr and OUT-ONr (as a rate per 300 m) in order to eliminate the influence of route section size.

4.2 Household Variables

The influence of different variables on transit ridership was investigated using simple correlation coefficients. This enables a quick assessment of many variables and variable combinations. Simple regression coefficients are presented in Table 3. Several observations can be based on the simple regression coefficients obtained for household variables:

a. The width of the land strip on each side of the bus route (catchment area) considered for transit trip generation should be at least 600 m (2000 ft) wide. The increase of width from 300 to 600 m (1000 to 2000 ft) had an influence on the simple correlation coefficients for variables IN-ON and total number of dwelling units similar to the increase of width from 150 to 300 m (500 to 1000 ft). According to Table 3, the simple correlation coefficient for variables IN-ON and the total number of dwelling units was 0.671 for the strip width of 150 m (on each side of the bus route). It increased to 0.698 for the strip width of 300 m and to 0.735 for the strip width of 600 m.

b. Single-family houses (i.e., dwelling units contained

TABLE 3/SIMPLE REGRESSION COEFFICIENTS

DESCRIPTION OF INDEPENDENT VARIABLE	DEPENDENT VARIABLE IN-ON[1]	DEPENDENT VARIABLE OUT-ON[2]
Total dwelling units 0 to 150 m from bus service	0.671	0.902
Total dwelling units 0 to 300 m from bus service	0.698	0.910
Total dwelling units 0 to 600 m from bus service	0.735	0.923
Dwelling units in single family houses, 0 to 600 m from bus service	0.712	0.922
Dwelling Units in multiple structures, 0 to 600 m from bus service	0.695	0.849
Apartments, 0 to 600 m from bus service	0.356	0.769
Best variable combining structural type of dwelling units and distance from bus service (defined by Equation 2 in text)	.762	
Car-owning households 0 to 600 m from bus service	0.674	0.789
Non car-owning households 0 to 600 m from bus service	0.768	0.912
Car-owning households +0.3 (non car-owning households), 0 to 600 m from bus service	0.778	0.930
Factory employment +9.5 (retail, office and other employment), 0 to 230 m from bus service	0.247	0.748
Secondary school enrollment +2.5 (post secondary school enrollment), 0 to 230 m from bus service	0.440	0.390
Peak headway in minutes	-0.458	-0.509
Logarithm of peak headway in minutes	-0.511	-0.515
Travel time ratio (transit travel time divided by car travel time)	-0.154	-0.241

1) IN-ON - total daily ridership, inbound-on, per route section

2) OUT-ON - total daily ridership, outbound-on, per route section

in single-family houses) and multiple-structure dwelling units (i.e., structures containing up to six dwelling units) exhibited a similar correlation with transit trip generation (R=0.712 and 0.695 for IN-ON in Table 3, respectively). The correlation between apartment dwelling units and transit trip generation was quite low (R=0.356). This may be explained by considering that large, economically active households, which are likely to generate more transit trips, usually occupy large dwelling units (such as single-family houses) rather than apartments.

c. No combination of structural-type household variables (single-family houses, dwelling units in multiple structures, and apartments) with the distance to bus service variables (strips of 0 to 150 m, 150 to 300 m and 300 to 600 m) could match correlation achieved by simple car ownership household variables. The combination variable (structural type with the distance from bus service) which had the highest simple correlation coefficient with the dependent variable IN-ON (0.762), was in the form:

$$\begin{aligned} &1.0\,(\,1.0\,SH(0\text{-}150) + 0.8\,SH(150\text{-}300) + 0.6\,SH(300\text{-}600)\,) \\ &+ 0.8\,(\,1.0\,\ M(0\text{-}150) + 0.8\,\ M(150\text{-}300) + 0.6\,\ M(300\text{-}600)\,) \\ &+ 0.5\,(\,1.0\,\ A(0\text{-}150) + 0.8\,\ A(150\text{-}300) + 0.6\,\ A(300\text{-}600)\,) \end{aligned} \quad (2)$$

where

SH = number of single-family houses per route section

M = number of dwelling units in multiple structures per section

A = number of apartments per section

Numbers in brackets indicate distance to bus service in metres. For example, SH(150-300) refers to the number of single-family houses which are in the range of 150 to 300 m from bus service.

In contrast, the car ownership household variable, H, in the form shown in Equation 3 achieved simple regression coefficient of 0.778 (Table 3).

$$H = 1.0\ NC + 0.3\ C \qquad (3)$$

where:

NC = number of non car-owning households within 600 m of bus service

C = number of car-owning households within 600 m of bus service

Moreover, the structural type household variables were based on 1976 data defined for small survey blocks while the car ownership household variables were based on 1971 data defined for much larger census tracts (Section 3.3). Also,the 1971 car ownership data were particularly weak for routes serving areas developed

after 1971. The superior performance of car ownership variables under these circumstances demonstrates the importance of car ownership data for transit demand modelling.

4.3 Other Variables

Similar analyses to those outlined in Section 4.2 for household variables were conducted for employment, school enrollment, and spatial-separation variables. Simple correlation coefficients for these variables are also presented in Table 3 and may be similarly interpreted.

5.0 MODEL DEVELOPMENT

Three direct transit trip generation and attraction models were constructed using a least squares technique. One model was constructed for prediction of inbound-on trips (number of passengers boarding buses travelling in the direction of the CBD) and two models for prediction of outbound-on trips (number of passengers boarding buses travelling in the direction away from the CBD).

In the case of peripheral routes, the direction of the CBD was assumed to be that toward the subway or subway connector. Assuming that the number of passengers getting on and off within one bus route section during a 24 h period is equal, the number of inbound-on daily trips is equal to the number of outbound-off daily trips, and the number of outbound-on daily trips is equal to the number of inbound-off daily trips. Consequently, using the models, directional passenger loadings on any route segment can be calculated.

The models predict ridership as a rate in terms of passenger trips per 300 m (1000 ft) of the route. The household, employment, and school enrollment data, originally collected on a route section basis, were expressed as a rate using the following equation:

$$\text{rate data} = \frac{\text{section data}}{\text{section length in metres}} \times 300 \text{ m} \qquad (4)$$

5.1 Inbound-On Model

The Inbound-On prediction model is basically a direct trip generation model which incorporates both the land use variables (households, employment, school enrollment) and a level-of-service variable (headway). A number of spatial-separation variables were tested in the model (e.g., ratio of the travel time by transit to the travel time by car, total transit travel time, distance to subway) but none was found to be statistically significant.

After an extensive calibration process, the following Inbound-On model was selected in view of its accuracy and simplicity.

$$IN\text{-}ONr = 64 + 1.09\ H + 0.18\ SCH + 0.02\ E - 43 \log HED \quad (5)$$

where:

IN-ONr = total daily ridership, inbound-on, per 300 m (1000 ft) long route segment

H = a combined number of car-owning and non car-owning households defined by Equation 3, per 300 m route segment

SCH = secondary school enrollment + 2.5 post secondary school enrollment, within 230 m (750 ft) of bus service, per 300 m long route segment

E = factory and warehouse employment + 9.5 retail and

office employment, within 230 m (750 ft) of bus service, per 300 m long route segment

HED = peak period route segment headway in minutes

The model applies to all route segments with the exception of the first segment adjacent to the subway or a subway connector, where it is assumed that no boarding in the inbound direction would occur. This is schematically illustrated in Figure 4.

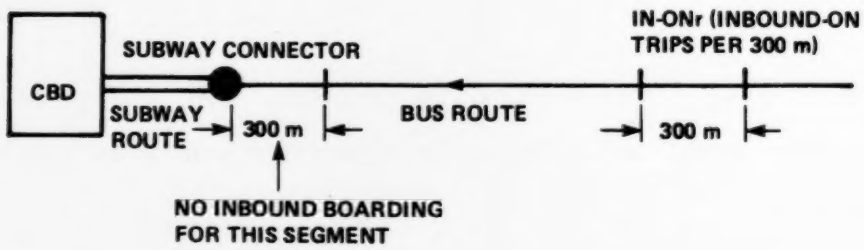

Figure 4/ Inbound-On Model

The statistical parameters of the model are summarized in Table 4. Figure 5 shows the relationship between the 1976 observed ridership and the ridership predicted by the Inbound-On model. It appears that the model has reasonable predictive power and a good degree of fit. The multiple correlation coefficient of 0.902 indicates that approximately 81 % (0.902^2) of the total variance is explained by the model.

Transit trip generation rates for the land use variables

TABLE 4/STATISTICAL PARAMETERS

MODEL	NUMBER OF OBSERVATIONS	STANDARD ERROR OF ESTIMATE (trips)	MEAN ESTIMATE (trips)	MULTIPLE CORRELATION COEFFICIENT
IN-ONr	74	70.5	153.0	0.902
OUT-ONa, Model A	11	397.0	3090.0	0.969
OUT-ONr, Model B	63	80.3	111.6	0.950

STATISTICAL SIGNIFICANCE OF PARTIAL REGRESSION COEFFICIENTS BASED ON T-TEST STATISTICS, SINGLE-SIDED TEST

VARIABLE	MODEL IN-ONr %	OUT-ONa MODEL A %	OUT-ONr MODEL B %
H (households)	0.5	0.5	0.5
E (employment)	5.0	5.0	N/A
SCH (enrollment)	0.5	0.5	N/A
HED (headway)	10.0	N/A	N/A
DR (distance ratio)	N/A*	N/A	10.0

*N/A - variable is not included in the model.

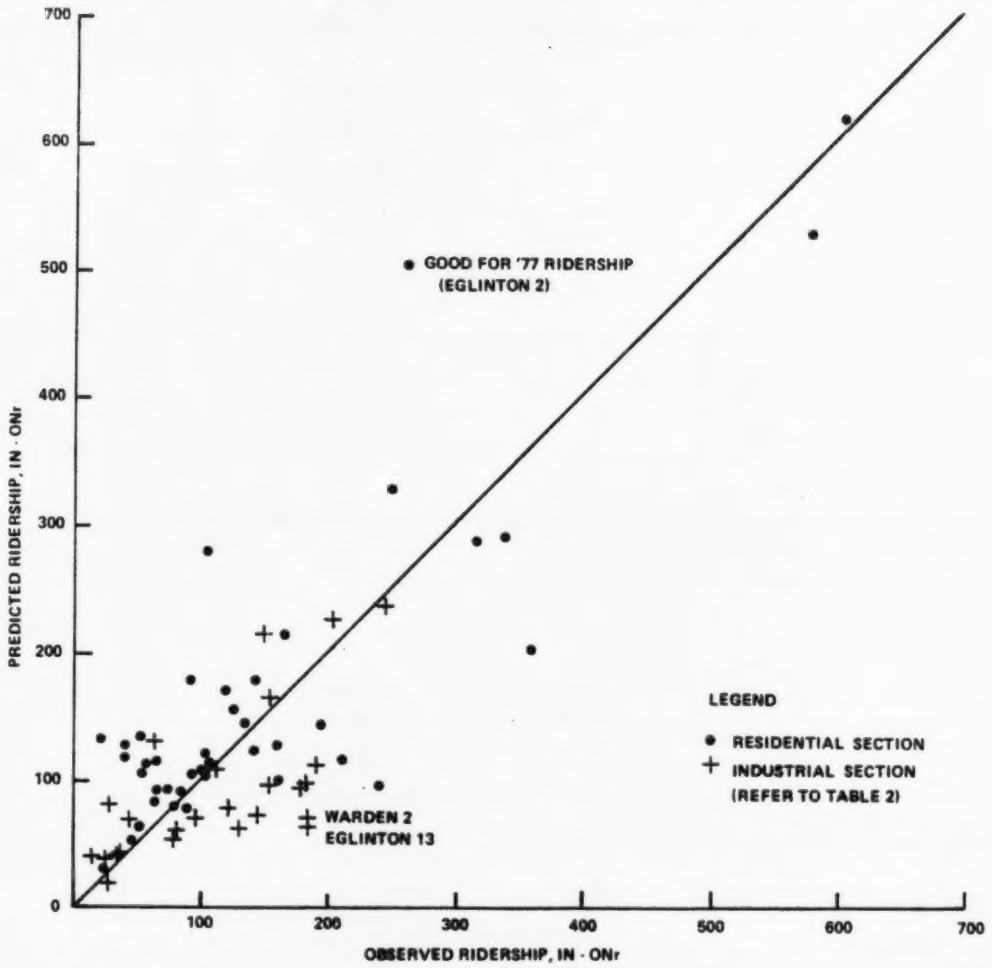

Figure 5/ Comparison of Observed and Predicted Ridership, Inbound - On, 1976

included in the model can be derived from the model's partial regression coefficients. The coefficient for variable H (households), 1.09 in Equation 5, suggests that, approximately, either one non-car-owning household or three car-owning households are required to generate one inbound transit rider. The coefficient for variable SCH (school enrollment) of 0.18 suggests that, approximately, 1 in every 5 secondary school students and 1 in every 2 post-secondary students generates one transit trip. Similarly, about 50 factory and warehouse employees or 5 retail or office employees generate one transit trip. The relationship between transit trip generation and level of bus service is included in the model as a logarithmic function of headway.

5.2 Outbound-On Models

Two Outbound-On models were developed; Model A and Model B. Model A predicts ridership for the first route segment adjacent to the subway or a subway connector only (e.g., streetcar at Queensway route). Model A takes into account the large number of passengers transferring from the subway and boarding buses in the first route segment. Model B predicts ridership for the remaining route segments.

5.2.1 Outbound-On, Model A

This model is essentially a transit trip attraction model and

applies only to the first 300 m (1000 ft) long route segment. It is assumed that all transfers between the subway and the bus route occur within this segment. The function of the model is schematically illustrated in Figure 6.

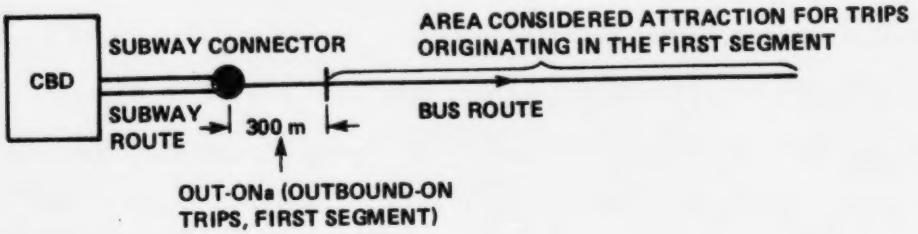

Figure 6/ Outbound-On, Model A

Land use along the rest of the route (households, school enrollment, and employment) acts as attraction for passengers transferring from the subway and boarding buses.

Outbound-On, Model A has the form:

$$OUT\text{-}ONa = 935 + 0.670\ H + 0.097\ SCH + 0.015\ E \qquad (6)$$

where:

OUT-ONa = total daily ridership, outbound-on, first segment

The variables H, SCH, and E were defined as previously for Equation 5. However, unlike in Equation 5, the variables H, SCH, and E are not expressed as rates per 300 m, but represent total amounts for the whole route.

The statistical parameters of the model given in Table 4 and the relationship between the predicted and observed ridership presented in Figure 7 indicate a very good degree of fit achieved by the model.

Transit trip generation rates for the three land use variables (households, school enrollment, and employment) are quite similar to the rates obtained for the Inbound-On model and may be similarly interpreted. However, the Outbound-On, Model A, does not include the effect of headways or any other level-of-service related variables. These variables were found to be statistically insignificant during the calibration process. This phenomenon may be due to data correlation — the existing headways being close to optimal. (High-ridership routes may have already short headways and low-ridership routes may have already correspondingly-longer headways.)

The model of Equation 6 may be used for estimation of total route ridership for bus routes originating from a subway.

5.2.2 Outbound-On, Model B

This model estimates the total daily number of passengers boarding buses in the outbound direction and applies to the whole route with the exception of:

a. the first 300 m (1000 ft) segment adjacent to the subway or subway connector where Model A applies, and

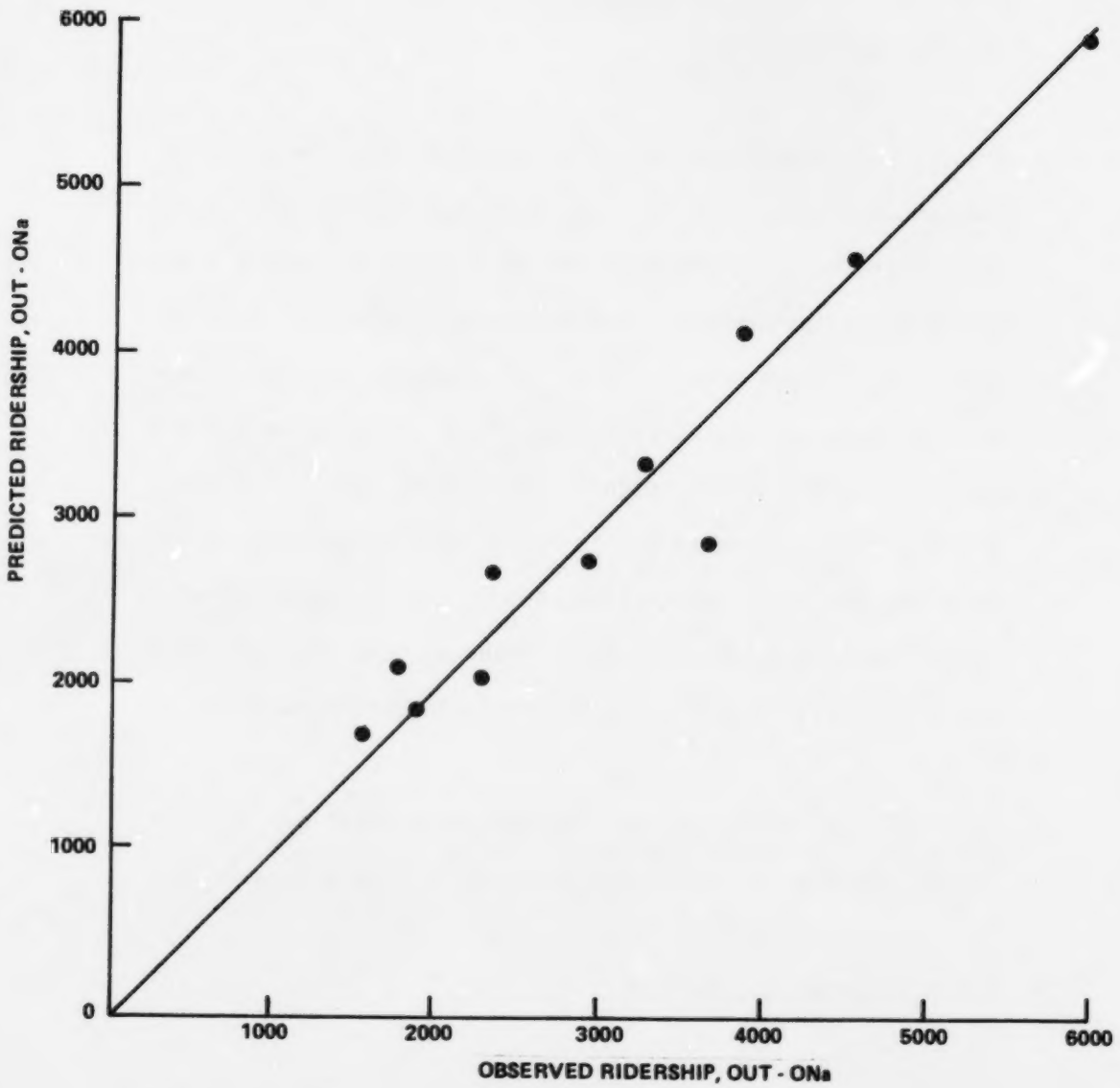

Figure 7/ Comparison of Observed and Predicted Ridership, Outbound - On, Model A

b. the last 600 m (2000 ft) long route segment where it is assumed that no boarding in the outbound direction occurs.

The function of the model is schematically illustrated by in Figure 8.

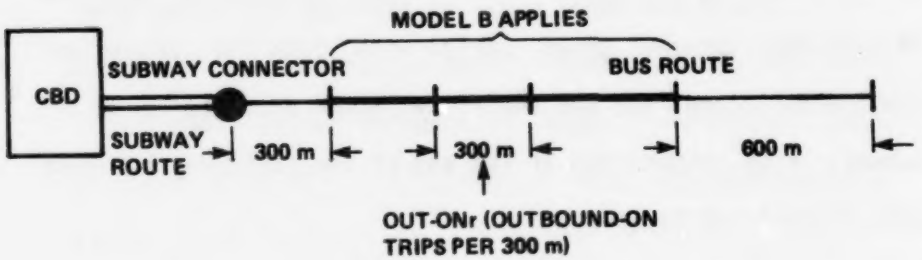

Figure 8/ Outbound-On, Model B

The model is basically a direct transit trip generation model in the form:

$$OUT\text{-}ONr = -6 + 1.183\,H + 0.022\,E - 57.0\,DR \qquad (7)$$

where:

OUT-ONr = total daily ridership, outbound-on, per 300 m route segment

H, E = (defined above for Equation 5)

DR = ratio of the segment's distance to the subway (or subway connector) to the total route length

Statistical parameters of the model are given in Table 4. Transit trip generation rates for variables H (households) and

E (employment) are again quite similar to the rates obtained for the Inbound-On model. Notable is the absence of variable SCH (school enrollment) in the model. This may be interpreted as a tendency for students to commute to schools located in the central part of the city rather than to schools located in the suburbs. The variable DR (ratio of the segment's distance to the subway to the total route length) indicates a reduction in outbound internal trips (trips with both the origin and destination along the bus route) with the distance from the subway. Trips originating at the end of the route may not have many attractions to go to.

6.0 DATA DEFICIENCIES

The success of model development and calibration depends on accuracy and reliability of input data. Several problem areas which were encountered during data collection and model calibration phases are summarized below.

a) Unreliable land use data in newly developed areas.

b) Household car ownership data, identified as the most significant factor influencing transit ridership, were obtained from old (1971) census data aggregated on a census tract basis.

c) Considerable ridership variation was observed between 1976 and 1977 ridership counts. The 1976 ridership data were used for model calibration. However, it was observed that in many instances the models were predicting 1977 ridership quite closely while differing considerably from 1976 ridership counts or vice versa. Figure 9 compares the 1976 and 1977 ridership counts for route sections identified in Table 2.

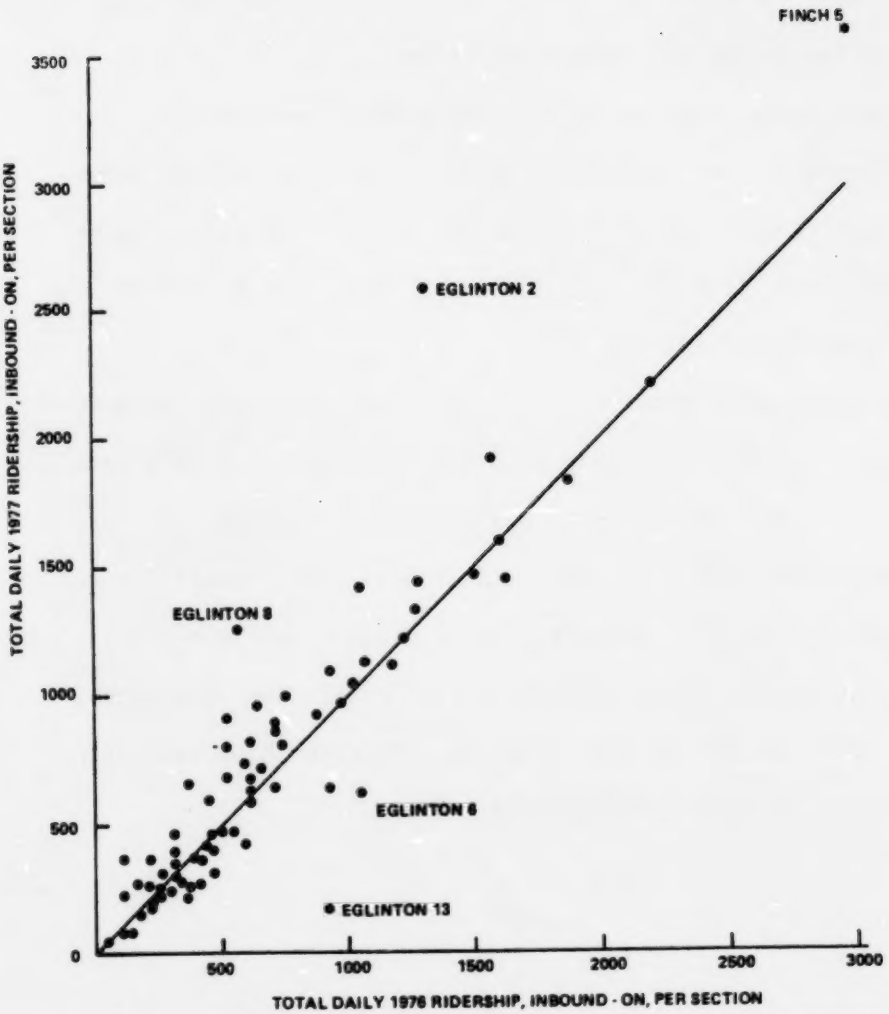

Figure 9/ Comparison of 1976 and 1977 Ridership Counts (Observed Ridership)

The standard error of estimate for the 1976 ridership counts, estimated using the 1977 counts, is presented below.

Variable Name (Defined Previously)	Std. Error of Est. 1976 vs 1977 Ridership (trips)	Std. Error of Est. Predicted vs Observed Ridership (trips)
IN-ONr	43.0	70.5
OUT-ONa(Model A)	228.5	397.0
OUT-ONr(Model B)	25.6	80.3

Thus, the standard error of estimate between the 1976 and 1977 ridership counts represents 30 to 60 % of the standard error of estimate between observed and predicted ridership obtained for the three transit trip demand models.

The observed ridership variation is not a data deficiency per se. It is discussed only to illustrate the extent of possible day-to-day ridership variation which can be used to assess the significance of variation between observed and predicted ridership (prediction error).

d) Unavailability of certain potentially significant variables such as household income and population age.

7.0 SUGGESTED MODEL USE

The models presented in this report can be used to predict transit ridership on individual bus routes enabling direct, objective cost-benefit comparison of alternative routes and route alignments. Since both the inbound and the outbound passenger boardings can be predicted, and assuming a balance between boarding and alighting passengers on a daily basis, it is possible to estimate directional loadings on any route segment.

The models are applicable to the Metropolitan Toronto area only. For application in other areas, the coefficients of the models should be obtained by calibration using local data.

8.0 CONCLUSIONS AND RECOMMENDATIONS

1. Transit demand models developed for Metropolitan Toronto can be used as operational models for ridership predictions on planned or modified bus routes. The models are relatively simple to use and utilize readily available data.
2. The model development and calibration process provided considerable knowledge regarding the effect of available land use and other variables on transit ridership. All available land-use variables influencing transit ridership were identified and evaluated.
3. Car ownership was identified as a key variable for predicting transit ridership. Reliable car ownership data are prerequisite for reliable prediction of transit ridership.
4. The model structure developed for Metropolitan Toronto may be used for other urban areas. The model coefficients should be obtained by calibration using local data.
5. The model coefficients should be verified by direct field testing. This can be accomplished by using the model to predict transit ridership on new or modified TTC bus routes and by its subsequent comparison with the achieved, and observed ridership. Also, the model structure should be tested by developing similar models for other urban areas.

9.0 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance received in all phases of the study from university students Roger Hanmer and Lawrence Wilcox. We are also grateful to Messrs. M. D. Harmelink and P.M. Dalton for helpful discussions in formulating and solving the problem.

10.0 REFERENCES

1. J. H. Miller, "Comparison of Demand Forecasting Techniques for Small Urban Transit Systems," Proc. Transportation Research Forum, Vol. 18, 1977, pp. 660-669.
2. R. Dobson, W. E. McGarvey, "An Empirical Comparison of Disaggregate Category and Regression Trip Generation Analysis Techniques," Transportation, Volume 6, 1977, pp. 287-307.
3. R. McGillvray, "Some Problems with Urban Transportation Planning Models Working Paper No.708-59, The Urban Institute, Washington, D.C., November 1971.
4. J. B. Peers, M. Bevilacqua, "Structural Travel Demand Models: An Intercity Application," Highway Research Board 569, 1974, pp. 124-130.
5. F. S. Koppelman. "Guidelines for Aggregate Travel Prediction Using Disaggregate Choice Models," Transportation Research Board Record 610, Washington, D. C., 1976, pp. 19-24.
6. P. W. Schmenner, "The Demand for Urban Bus Transit - A Route-by-Route Analysis," Journal of Transport Economics and Policy, Volume 10, January 1976, pp. 68-86.
7. J. H. Shortreed, "A Transit Demand Model for Medium-Sized Cities," Report DOT-OS-30093, NTIS, Springfield, Virginia, 22151, Dec. 1975, pp. 1-89.
8. J. H. Shortreed,D. Maynes, "Calibration of a Transit

Demand Model for Kitchener-Waterloo," Report on Project WRJ 606-11 for Ontario Ministry of Transportation and Communications, University of Waterloo, Waterloo, Ontario 1977, pp. 1-80.